Population Boundaries for Galactic White Dwarf Binaries in LISA's Amplitude-Frequency Domain

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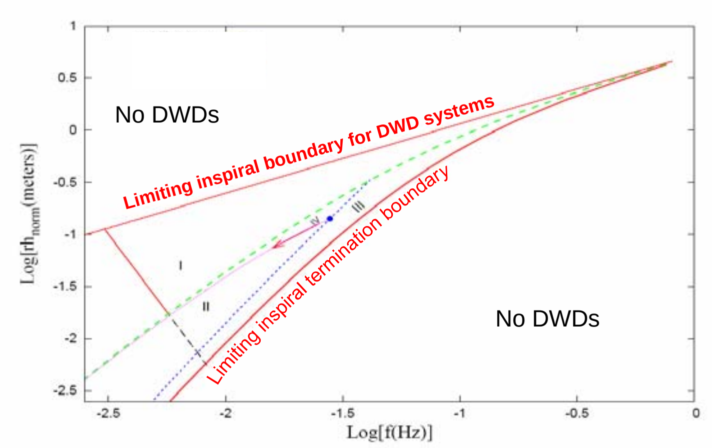
Abstract

Double white dwarf (DWD) binary systems are considered to be among the most promising sources of gravitational waves for LISA. The path that DWD binaries traverse across LISA's "absolute" strain-frequency domain during the detached, inspiral phase of their evolution is well-understood. Theoretical constraints on the properties of the white dwarf stars also allow us to map out the evolutionary trajectories of DWD binaries during a phase when they are semi-detached and undergoing stable mass transfer. We have identified population boundaries that define distinct sub-domains in LISA's strain-frequency diagram where inspiraling and/or mass-transferring systems will and will not be found; sub-domains where progenitors of Type Ia supernovae reside also are identified. We identify for what subset of these populations it should be possible to measure frequency shifts and, hence, directly follow orbit evolutions, given LISA's anticipated operational time. We show how such measurements should permit the determination of binary system parameters, such as luminosity distances and chirp masses, for mass-transferring as well as inspiraling systems.



Astronomers are accustomed to measuring the “apparent” magnitude *m* of a star then, once the distance to the star is known, they convert *m* to an “absolute” magnitude *M*, which gives a measure of the intrinsic brightness of the source. In a similar fashion, the apparent brightness of a gravitational-wave (GW) source will be initially determined by a measurement of the GW-strain *h*, and a knowledge of the source distance *r* can be used to determine the product *rh*, which provides a measure of the *intrinsic* brightness of the GW source. Emphasizing this analogy with astronomical nomenclature, here we will refer to *h* as the “apparent” GW-strain and will refer to the quantity “*rh*” as a measure of a system’s “absolute” GW-strain.

As the above figure illustrates, we can use our understanding of the various stages of Double White Dwarf (DWD) binary evolutions and the properties of individual white dwarfs to divide LISA’s “absolute” strain-frequency parameter space into four distinct sub-domains.

Region I : A DWD system found in this region must be evolving through the “inspiral” phase of its evolution and changes in its GW-frequency should be measurable within one year. The top (red) line represents the inspiral trajectory of a system having $M_a=M_d=M_{chandra}$; hence, no DWD system can exist above it.

Region II : DWD binaries in this region can either be inspiralling or mass-transferring systems, but all will show a measurable frequency change within one year**.** The (red) curved boundary to the right represents the locus of inspiral termination points for equal-mass systems where the donor just fills its Roche lobe. This curve serves as a boundary because further evolution of the system guides it to lower frequencies due to mass transfer. Systems with unequal mass stars have inspiral termination points that lie to the left of this bounding curve, hence no DWD system can exist to the right of it. The upper (green curved) boundary of this region is defined by mass-transferring systems in which the accretor has reached the limiting mass, $M_{chandra}$; no mass-transferring DWD systems can exist above this green dashed curve.

Region II can be further subdivided into **Regions III** and **IV**.

Region III : Mass transfer can be stable or unstable. The blue straight line represents the boundary between stable and unstable mass-transferring systems. A DWD which lies to the right of this boundary, i.e in **Region III**, will undergo unstable mass transfer and may have a violent ending. All mass-transferring systems between the blue and green curves undergo an extended period of stable mass transfer; AM CVn is the prototype for such systems.

Region IV : For stable mass-transferring systems with M_{tot} greater than or equal to $M_{chandra}$, the accretor's mass will eventually exceed the Chandrasekhar mass limit; this will likely result in a Type Ia supernova explosion. The progenitors of Type Ia supernovae will therefore be confined to **Region IV**, whose lower boundary is defined by the evolutionary trajectory (pink curve with an arrow) of a mass-transferring DWD system that has $M_{tot} = M_{chandra}$ and originates at the blue line. The green and blue curves provide the additional boundaries of this region.

LISA’s measurements of *h* and *f* will have to be supplemented by a determination of the distance *r* to each DWD system in order for the sources to be mapped onto an “absolute” strain-frequency diagram to reveal how they align with the above-described population sub-domains. Fortunately, as mentioned above, all DWD systems in **Regions I** and **II** will exhibit frequency evolutions within one year of observation, which should permit a determination of *r* for each system.

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